IMAGING OF A COMPLETE SAMPLE OF IR-EXCESS PG QSOS

Jason A. Surace (SIRTF Science Center/Caltech)
and D.B. Sanders (Institute for Astronomy, University of Hawaii)

1. Background

Sanders et al. (1988) proposed an evolutionary connection between Ultraluminous Infrared Galaxies (ULIGs) and optically-selected QSOs. In this scenario, mergers of dust and gas-rich galaxies provide the fuel to create and/or fuel an AGN and circumnuclear starburst. This dust completely enshrouds the AGN, and subsequent reradiation of the short-wavelength AGN emission produces the high far-IR luminositiy that defines ULIGs as a class. Dust clearing by superwinds eventually begins to unveil the central AGN, which is then perceived as a QSO. Surace et al. (1998, 2000) carried out a comprehensive program of multi-wavelength high spatial resolution observations using *HST* and ground-based tip/tilt in order to characterize the morphology and colors of ULIGs. Particular emphasis was given to ULIGs with "warm" mid-IR colors, whose spectral energy distributions (SEDs) and emission line features suggested that they were the most evolved ULIGs in the process of becoming QSOs. These studies showed that ULIGs were the merger of two L^* galaxies, and that they had compact central sources whose luminosity and colors are similar to reddened AGN. They also possess "knots" of star formation distributed in the circumnuclear regions and along the merger-generated tidal debris.

2. Infrared-Excess QSOs

During the evolutionary process, the SEDs of these mergers must evolve from the ULIG far-IR dominated spectra towards those with a strong relative optical/UV component. Therefore, QSOs with strong contributions to their total luminosity from far-infrared emission should be less evolved and more similar to the ULIGs than QSOs in general.

A complete sample of 18 QSOs was selected from the Palomar-Green Bright Quasar Survey (Schmidt & Green 1983), which at the time had

the most complete published infrared data. They lie at the same distances ($z<0.16$) as previous samples of ULIGs examined by Surace et al., thus alleviating resolution dependencies in interpreting the data. ULIGs are defined to have the same minimum bolometric luminosity ($10^{12} L_\odot$) as QSOs, as defined by Schmidt. Far-infrared data from IRAS was used to evaluate the contribution to the bolometric luminosity of the "big blue bump" (0.1—1 μm; L_{BBB}) relative to that emitted in the far-IR at 8—1000 μm (L_{IR}). All the QSOs with far-IR excesses (L_{IR}/L_{BBB}) as great as the least far-IR active ULIG (3C 273; L_{IR}/L_{BBB}=0.46) were selected. A campaign of high resolution observations at B, I, H, and K' using a fast tip/tilt guider on the UH 2.2m telescope was carried out on 17 out of the complete sample of 18 objects. Typical spatial resolutions at H and K' were 0.25″ while those at B and I were 0.7″ . The data were either photometric or were tied to that of Neugebauer et al. (1987) so that colors could be derived.

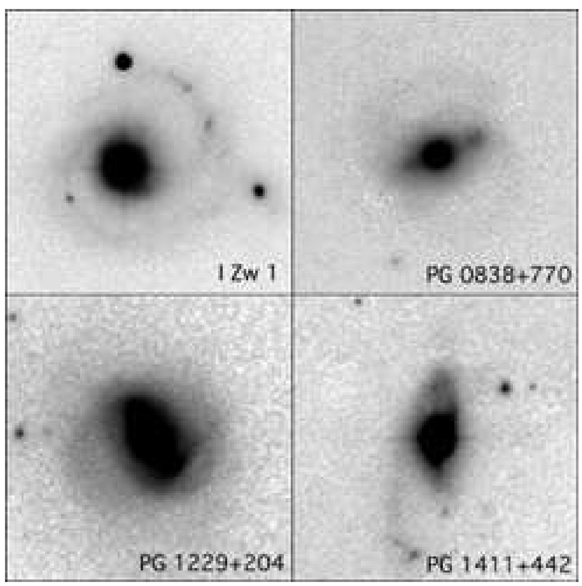

Figure 1. Optical images showing the diversity in host galaxy morphology of Infrared-Excess PG QSOs, including a spiral galaxy, two barred spirals, and a major merger with an 80 kpc tidal tail.

3. Results

1) All of the IR-excess QSOs have readily detectable hosts. Their morphologies are varied, but at least 50% are spiral-type systems, as evidenced by the presence of spiral arms, and just over half of these

are barred. This is similar to results for Seyfert galaxies and radio quiet quasars (McLeod & Rieke 1994/95; Taylor et al. 1996). The variance between this result and other recent imaging studies (McLure et al. 1999), which have found a predominance of elliptical-like hosts, is probably due to selection effects. Our infrared criterion selects galaxies with significant reservoirs of gas and dust (Evans et al., this vol.) and is known from *IRAS* to strongly select spiral galaxies. Furthermore, the sample does not match the luminosity *distribution* of the Surace et al. ULIGs. Instead, the demand for low redshift systems selects the least-luminous QSOs, as opposed to the higher-luminosity samples used by others.

2) The mean H-band luminosity of the (point-source subtracted) host galaxies is 2.2 L^*. The distribution of host galaxy luminosities for "warm" ULIGs and QSOs is nearly identical.

3) 22% are in major merger systems. An additional 25% have barred morphologies that are consistent with late-stage minor merger morphologies. The total number of host galaxies where mergers may be implicated is thus between 25—50%. The remaining 25% with indeterminate or elliptical-like features may also be merger remnants.

4) Several have small-scale (<1 kpc) structure similar to that seen in ULIGs; these knots are typically very red and are similar to dust-enshrouded star formation with an age of $\leq$ 100 Myrs. The QSO nuclei also have near-IR excesses (beyond dust-reddening) which may be the result of small amounts of hot thermal dust emission.

5) These results imply that while some 25% of IR-excess QSOs have morphologies consistent with advanced mergers, another 25% (apparently unperturbed spiral galaxies) cannot have had their infrared activity triggered via the major mergers implicated in the formation of ULIGs. A more thorough understanding of these statistics will necessitate similar obervations of the complementary sample of non-IR-excess QSOs. A larger complete sample of QSOs with greater counting statistics would also be useful.

References

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